

The Use of Mild-Gain Hearing Aids for Adults with Hearing Difficulties

Senior Thesis

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Speech and Hearing Science in the undergraduate colleges of The Ohio State University

By

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Abstract

An auditory processing disorder (APD) has been defined as a perceptual issue affecting the way in which the central auditory nervous system understands and makes use of auditory information [American Speech-Language-Hearing Association (ASHA), 2005; American Academy of Audiology (AAA), 2010]. The primary complaint of individuals with APD is difficulty understanding speech in background noise, often in the presence of normal pure tone thresholds (Whitelaw, 2008). Adults with subject listening complaints consistent with APD have been referred to as having ‘hearing difficulties’ (HD) (Tremblay et al., 2015). Recent research has shown improvements in speech-in-noise performance for children with APD (Kuk et al., 2008) and for adults with subjective HD (Moore, 2015) when using mild-gain hearing aids. The purpose of this study was to examine the benefit of a four-week trial with mild-gain hearing aids for adults with HD. Seven adults with HD and ten control adults (18-59 years) participated. All participants had normal pure tone thresholds. Inclusion criteria for HD participants included: ≥ 20 on the Hearing Handicap Inventory for Adults (HHIA; Newman et al., 1990), and abnormal performance on one or more tests in an auditory processing test battery. Subjective auditory processing abilities were measured using the Auditory Processing Questionnaire (APQ). Speech-in-noise performance was measured using the Revised-Speech Perception in Noise test (R-SPIN; Bilger et al., 1984). Once enrolled, the HD participants were seen for two additional sessions: 1) baseline R-SPIN testing and hearing aid fitting, and 2) post-trial aided R-SPIN testing, HHIA and APQ. Participants were fitted with receiver-in-the-canal hearing aids with 5-10 dB of gain for low to moderate inputs, and no gain for high inputs. The hearing aids were programmed with noise-reduction and directional microphones engaged. Control participants completed the HHIA, APQ and R-SPIN. Results revealed a significant difference between

subjective auditory processing abilities (APQ), hearing handicap (HHIA) and speech-perception-in-noise (R-SPIN) performance between the control and HD groups. Results also revealed a significant difference between HD unaided and HD aided R-SPIN testing. Future research should include: a larger sample size, assessing other factors in HD individuals (i.e. listening effort, working memory, attention etc.) and a comparison of other treatment options to the mild-gain hearing aids (i.e. FM systems, auditory training etc).

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Chapter 1

Introduction and Literature Review

Auditory processing disorder (APD):

According to the American Academy of Audiology (AAA), an auditory processing disorder (APD) can be described as a diverse neurological disorder affecting the way in which the central auditory nervous system (CANS) understands and makes use of auditory information, thus impacting how the brain processes spoken language. APD is seen in a wide range of populations and can be the result of a number of different etiologies that involve deficits in the function of the CANS. The underlying cause(s) of APD, however, is still unclear. APD presents with a wide range of symptoms that can affect an individual's academic, occupational, behavioral and social life (AAA, 2010). These symptoms can include but are not limited to: difficulty understanding speech in the presence of background noise, difficulty with the ability to localize the source of a signal, inconsistent or inappropriate responses to requests for information, difficulty hearing on the phone, difficulty following directions, frequent requests for repetition of information, difficulty or inability to detect the subtle changes in prosody that underlie humor and sarcasm, difficulty learning a foreign language or novel speech materials, difficulty maintaining attention, a tendency to be easily distracted, and academic difficulties in reading, spelling and/or learning problems (AAA, 2010).

Diagnosing APD:

The recommended evaluation of and the diagnostic criteria for APD vary according to the source, most likely due to the unknown etiology and varying presentations. For example, both the American Speech-Language-Hearing Association (ASHA) and AAA suggest using both

speech and non-speech tasks in order to assess different regions of the CANS and different auditory abilities, including: sound localization and lateralization, auditory discrimination, auditory temporal processing, auditory pattern processing, dichotic listening, auditory performance in competing acoustic signals, and auditory performance with degraded acoustic signals. On the other hand, some researchers argue for the same assessments using strictly non-speech stimuli to avoid the misdiagnoses of a language disorder as APD (Dawes & Bishop, 2009). Due to the varying difference in opinions on what tests should be used, retrospective studies have been conducted to examine APD diagnostic criteria itself and how many individuals will receive a diagnosis based on the criteria used.

Wilson and Arnott (2013) conducted a retrospective review of 150 children between the ages of 7.0-15.6 years with normal peripheral hearing who had completed a central auditory processing (CAP) assessment. Nine different diagnostic criteria were used to determine whether the child did or did not have APD. Depending on the criteria used, rates of APD diagnosis ranged from 7.3%-96.0%. The lowest diagnosis rate (7.3%) was observed for failing tests in a pattern following Bellis (2003) primary APD subprofiles. To meet the Bellis APD criterion, an individual would have to be consistent with one of four subprofiles: (1) auditory decoding deficit, (2) prosodic deficit, (3) integration deficit. (4) both auditory decoding deficit and integration deficit. The highest APD diagnosis rate (96.0%) criterion came from ASHA (2005). The ASHA APD diagnosis stated that an individual must fail one or more test (including monaurally failure) within at least one (C)AP domain. Wilson and Arnott did not discuss a preferred method of APD diagnosis. Their results, however, illustrate the problem of underdiagnosing, over diagnosing and the ambiguity of APD depending upon the diagnostic criteria.

Populations that present with APD

APD can be found in variety of populations and across all age ranges. According to audiologic literature, the following populations have thus far presented with APD: children (Bamiou et al., 2001), adults (Baran, 2002), older adults (Fire et al., 1999), adults exposed to high-intensity blasts and/or traumatic brain injuries (TBI) (Fausti et al., 2009; Gallun et al., 2012; Saunders & Haggard, 1989). Researchers have used various labels to describe adults who present with symptoms consistent with APD, including obscure auditory dysfunction (OAD; Saunders & Haggard, 1989) auditory disability with normal hearing (Stephens & Rendell, 1988), King-Kopetzky syndrome (KKS; Hinchcliffe, 1992), idiopathic discriminatory dysfunction (Rappaport et al., 1993), and most recently, hearing difficulties (HD; Tremblay et al., 2015). In general, these labels describe individuals with normal hearing who reported substantial difficulty understanding speech-in-noise, difficulty maintaining attention, academic difficulties, etc. Because these individuals perform normally on routine measures of auditory function (e.g., pure tone thresholds, speech-in-quiet, etc.), they often do not receive a diagnosis and are told they have normal hearing.

HD is the most recent term used to describe a group of adults experiencing difficulty understanding speech in acoustically complex environments (e.g., background noise, multiple talkers) in the presence of normal hearing sensitivity (Tremblay et al., 2015). The authors who coined that term identified a subset of participants with normal hearing from the Beaver Dam Offspring Study that self-reported HD using the Hearing Handicap Inventory (HHI; adult and elderly screening versions). Four questions were pulled from the original HHI in order to determine inclusion into the HD group. Of the 686 participants with normal hearing, 12% of individuals aged 21-67 years reported HD, resulting in an overall prevalence of 2.9% among all

participants (including those with hearing loss). The co-morbid factors potentially contributing to HD in the Tremblay et al. study included noise exposure, likelihood of depression and reduced vision, as well as symptoms of neuropathy. Therefore, further research regarding the assessment and management of individuals with HD, as well as contributing factor is still needed (Tremblay et al., 2015).

A 1989 study by Saunders and Haggard used the term OAD to describe the clinical presentation of reported difficulty understanding speech in the presence of noise with normal audiometric thresholds and no other obvious causes (Saunders & Haggard, 1989). Twenty patients were matched with twenty controls based on the following factors: age, sex, educational level and noise exposure. Each matched pair was then compared on tests of auditory, linguistic, and psychological function. OAD subjects had 25% poorer speech reception thresholds in noise as compared to the control subjects. However, the study concluded that no single factor (auditory, linguistic, or psychological) clearly predominated in distinguishing the OAD subjects from controls. Because no single factor predominated, Saunders and Haggard recommended that OAD must be viewed as a multifactorial disorder that incorporates auditory, linguistic, and psychological aspects.

OAD, HD, and APD represent a population with similar subjective complaints that are not yet fully understood. Unless otherwise specified, individuals from the present study will be referred to as those with HD. However, regardless of the terminology used to describe individuals from this population, complaints of difficulty understanding or attending to auditory information in the presence of normal pure-tone thresholds should not be ignored or left untreated. Even though these individuals may have non-auditory factors (e.g., attentional deficits, loss of inhibition, etc.) that contribute to their HD, they present in audiological settings

because of difficulty understanding speech. These non-auditory contributions may be due to environmental factors (i.e. head/brain injuries; Fausti et al., 2009) or personal (i.e. personality traits, e.g., neuroticism). Even a personal factor such as cognition has been shown to affect a person's perceptual abilities (Craik, 2007). Therefore, HD may relate to a broad range of variables that at times fall outside the traditional scope of audiology, but are likely to be helped when addressed with aural rehabilitative services.

Psychosocial Impact of APD and HD

Deficits in auditory processing are complex and the manner in which they affect daily life varies. Both clinical experience and research evidence demonstrates that those with APD experience negative psychosocial consequences. For example, a research study by Keith and Purdy (2014) showed that parents of children with APD reported their child as having low self-esteem or a sense of inadequacy. Keith and Purdy also indicated that children with APD often experience frustration at their inability to learn despite effort, and may exhibit anxiety or become withdrawn.

Depression has also been linked to adults with subjective HD. For instance, in the Tremblay et al. (2015) study, control and HD subjects were assessed using the Center for Epidemiological Studies-Depression (CES-D; Radloff, 1977), a 20-item self-report depression scale used to probe symptoms of depression such as: restless sleep, poor appetite, and feeling lonely. Mean CES-D (depression) scores fell within the normal range for both control and HD groups. However, people who reported HD were more likely to have a CES-D total score of 16 or greater (the recommended cutoff score for those with depression being 16). Therefore, if patients with HD are left untreated, psychosocial impacts to individual's life may occur more often than in those without HD (Tremblay et al., 2015).

Management of APD and HD:

APD is typically associated with young children and aging adults, and as a result many treatment options have been explored. APD in children is typically treated with classroom modification strategies, the use of a personal FM system, and supplementation of visual aids alongside auditory materials (Rosenberg, 2002).

One of the most common treatments for children with APD, is the use of personal FM systems. Johnston et al. (2009) fitted Phonak EduLink FM devices on children with APD for both home and classroom use. Baseline measures of the participants documented significantly lower speech-perception scores, evidence of decreased academic performance, and psychosocial problems in comparison to an age- and gender-matched control group. The Johnson et al. study made repeated measures during the school year that showed speech-perception improvement in noisy classroom environments as well as significant academic and psychosocial benefits. This study also demonstrated that after prolonged FM use, even unaided speech-perception performance improved in the subjects, suggesting that the FM systems enhanced auditory system function (Johnston et al., 2009). Although FM systems have proven to be useful, recent years' research has also suggested the use of hearing aids for children with APD.

A 2008 single-blind, longitudinal descriptive study by Francis Kuk and colleagues in which subjects were between the ages of 7-11 years set out to examine a new treatment for children with APD, mild-gain hearing aids. The purpose of this study was to determine whether the mild-gain hearing aids would improve speech-in-noise performance and daily functioning in children with APD. No control group was collected and each subject served as his/her own control in various hearing aid conditions. Each subject wore bilateral, mild-gain, behind-the-ear style hearing aids that provided 10 dB of real-ear gain for soft sounds. Participants were

encouraged to wear the hearing-aids in a multitude of settings and were seen four times. Children were evaluated using the Northwestern University Auditory Test Number Six (NU-6) Auditory Continuous Performance Test (ACPT) in noise, and the subjective Children's Auditory Performance Scale (CHAPS) questionnaire both before and at the end of the study. Results showed a significant difference in the ACPT error scores among testing conditions (unaided, aided, ACPT in quiet, and ACPT in noise). Therefore, results indicate that the mild-gain hearing aids improve speech identification in noise (i.e. ACPT in noise). Kuk et al. also showed subjective improvements after gathering impressions from participants and their parents by using the CHAPS. Many parents felt that the hearing-aids helped improve their child's focusing skills, grades, and ease of listening in background noise (Kuk et al., 2008).

In contrast, APD seen in older adults is often accompanied by peripheral hearing loss which contributes to their auditory processing difficulties. Treatment for APD in aging adults includes aural rehabilitation, use of a personal FM system, auditory training programs and hearing aids (Chmiel & Jerger, 1996).

Treatment options for young to middle-aged adults have not been fully explored until recently in a study conducted by Moore (2015). The purpose of Moore's study was similar to the Kuk et al. (2008) study and was designed to investigate the effect of mild-gain hearing aids with directional microphones and noise reduction in adults with auditory processing difficulties. Eleven adults were recruited with normal audiometric thresholds but complaints and case history consistent with APD. Each participant completed two tests in order to objectively measure the subject's auditory processing abilities: SCAN-3A (a clinically based APD test battery; Keith, 2009) and the Revised-Speech Perception in Noise (R-SPIN). The R-SPIN was given under two conditions: equipped with mild-gain amplification and equipped without to determine objective

speech perception in noise. They were also evaluated using two subjective questionnaires about self-perceived hearing abilities: The Hearing Handicap Inventory for Adults (HHIA) and revised CHAPS. Moore's results showed a decrease in perceived anxiety and significant improvements in R-SPIN recognition performance during aided testing. A limitation of Moore's study is that the listeners with HD only wore the hearing aids in the lab during testing. It would be helpful to know if the benefits of mild-gain amplification seen in Moore's study can be translated to real-world listening.

Benefits of directional microphones and noise reduction:

One problem all listeners face is the effect of background noise on speech perception. As indicated in several studies, those with subjective HD experience even more difficulty in noise (Tremblay et al, 2015; AAA, 2010; Fausti et al, 2009; Saunders & Haggard, 1989). With the advancement of hearing aid technology, however, improvements in speech understanding in noise are possible. An example of this advancement in hearing aid technology is the addition of directional microphone algorithms and noise reduction schemes.

Directional microphones in hearing aids were introduced to the European market during the late 1960s and came to the U.S. market during the early 1970s (Bentler, 2005). Soon after, an overwhelming number of studies were conducted in order to examine the function and benefit of directional microphones for hearing aid use. A recent systematic review of evidence was conducted by Bentler (2005) to examine both directional microphones and noise reduction schemes. Nine studies were identified for directional microphones. Based on the nine identified studies, Bentler concluded that directional microphones generally resulted in improved subjective benefits and caused a reduction in communication problems.

One study in particular investigated the effect of directional microphones on speech perception-in-noise for open fit behind-the-ear hearing aids in a group of 16 hearing impaired participants (Klemp & Dhar, 2008). Aided speech-perception-in-noise testing was conducted using omnidirectional and directional microphone modes, as well as an unaided condition. Results revealed that recognition performance in noise was better in the unaided condition relative to the omnidirectional condition. When unaided performance was compared to the directional microphone condition, however, recognition performance improved. The authors reported a directional advantage of 2.6 dB for open fit hearing aids. The results from the Klemp and Dhar study provide evidence to support the efficacy of directional microphones in fitting open fit hearing aid fittings.

Over 20 years ago, noise reduction (NR) schemes were promoted as hearing aid technology that would improve listening comfort and be a solution to understanding speech in noise. However initial research about NR schemes has not supported these claims. Little research exists on NR schemes, but several research studies have suggested that NR has not been shown to improve speech understanding. Conversely, evidence does exist to support the claim that NR improves an individual's listening comfort (Bentler, 2005). Therefore, Bentler concluded that noise reduction features should still be implemented because of hearing aid users' improved listening comfort.

Potential benefits of the present study

Subjective HD in the presence of normal audiometric thresholds has become an area of interest in recent decades. One potential benefit of the present study is to provide an evidence-based treatment for young to middle-aged adults who may be experiencing HD, regardless of the presence of an APD diagnosis or an individual's experienced symptoms.

Another benefit of this study is to provide an alternative treatment to individuals with HD other than the use of personal FM systems. FM systems have been shown to be successful for those with APD (Jeger et al., 1996), however FM systems are often rejected because of difficulty of use, dependency on the speaker, and cosmetic issues such as size and appearance of the device. Unlike FM systems, the mild-gain hearing aids provide a treatment option that is well suited for real-life scenarios, offer the benefits of NR schemes and directional microphones, and are more cosmetically appealing.

Purpose

The goal of the current study was to expand upon Moore's (2015) findings by further investigating the potential benefits of amplification through a four-week trial with mild-gain hearing aids equipped with noise reduction and directional microphones in a group of adults with subjective HD. A secondary purpose of the present study was to demonstrate that a group of adults with subjective HD comprise a population that is both subjectively and objectively different from typical or normal listeners (i.e., a control group). Therefore, the specific goals of this project were as follows:

1. To determine if the use of mild-gain hearing aids facilitated a measurable improvement in objective measures of speech-in-noise for adults with HD;
2. To determine if the use of mild-gain hearing aids resulted in a self-perceived improvement in hearing handicap and auditory processing abilities for adults with subjective HD in their day-to-day environments;

3. To determine if the use of mild-gain hearing aids resulted in a perceived decrease in anxiety when experiencing speech-in-noise environments for adults with subjective HD.
4. To determine if a group of adults with subject HD demonstrate significantly poorer self-perceived hearing handicap and auditory processing abilities, as well as significantly poorer speech-in-noise abilities relative to a group of control subjects.

Chapter 2

Methods

Subjects:

Seventeen adult participants were recruited for the present study. Ten participants (1 male and 9 female) 19-24 years of age (mean = 21 years) served as control subjects. Seven participants (2 male and 5 female) 20-49 years of age (mean = 32.4 years) with subjective HD served as experimental subjects (the HD group). Inclusion criteria for the study were as follows: 1) pure tone thresholds ≤ 25 dB HL 250-8000 Hz (one subject had a 30 dB HL threshold at 500 Hz) with no significant air-bone gaps (< 10 dB HL) at 500- 4000 Hz; 2) a negative family history of hearing loss; 3) negative history of middle-ear pathology; 4) normal otoscopy; 5) tympanometry within normal limits (Margolis & Hunter, 2000); 6) present ipsilateral acoustic reflexes; and 7) native speaker of English. Additional inclusion criteria for the HD group included a score of ≥ 20 on the HHIA (mean HHIA = 37.7). The control group was recruited to provide normative data on the experimental task. The control group had HHIA scores < 20 (mean HHIA = 0) to ensure no presence of hearing handicap among this group.

The present study was approved by the Ohio State University (OSU) Biomedical Sciences Institutional Review Board. Subjects were recruited via the OSU Hearing Clinic and flyers posted on and around the Ohio State University campus. Advertisements were also distributed electronically through the Ohio State University email newsletter OnCampus Today. Subjects were compensated for their time.

Materials:

Two subjective questionnaires were used to determine and quantify the subject's self-perceived hearing abilities: HHIA and Auditory Processing Questionnaire (APQ). The HHIA (Newman et al., 1990) is a subjective questionnaire designed to assess the perceived handicap that an individual experiences as a result of a hearing problem. There are 25 questions, 12 addressing the social impact of a hearing problem and 13 addressing the emotional impact of hearing problem. The subject is asked to check 'Yes' (4 points), 'Sometimes' (2 points), or 'No' (0 points) for each question. There are 48 points possible for social impact questions and 52 points possible emotional impact questions such that scores range from 0-100. The following ranges describe the handicap experienced; 0-16% = no handicap, 18-42% = mild-moderate handicap, and 44%+ = significant handicap. The APQ is a subjective questionnaire that was restructured from the CHAPS (Smoski et al., 1998). Specifically, the instructions were rewritten to be appropriate for an adult (Lamoreau, 2012). The APQ assesses the level of difficulty an individual experiences in various listening conditions on a 7-point Likert scale where 0 = never and 6 = always. There is a total of 36 questions across five listening conditions, including noise, quiet, ideal, auditory memory/sequencing and auditory attention span. Scores range from 0 to 216 with lower scores indicating few self-perceived auditory processing difficulties.

The R-SPIN test (Bilger, Nuetzel, Rabinowitz, & Rzeczkowski, 1984) was used to measure the speech recognition-in-noise abilities of subjects for the present study. The R-SPIN is composed of high and low predictability sentences presented in the presence of background noise. The R-SPIN requires the participant to listen to the sentences and background noise and respond by repeating the last word in each sentence. High predictability sentences provide context, which allows the last word (the target word) of the sentence to be reasonably predicted.

An example of this would be: “Stir your coffee with a *spoon*.” Low predictability sentences are ones in which the target word cannot be predicted based on sentence on the context provided. An example of this would be; “Nancy considered the *sleeves*.”

Auditory processing test battery

The auditory processing test battery was used in order to have an objective measure of the auditory processing abilities of an HD subject. The auditory processing test battery was comprised of the following four tests: SCAN 3:A (Keith, 2009), 500-Hz masking level difference (MLD; Wilson et al., 2003), Gaps-in-Noise test (GIN; Musiek et al., 2005) and Dichotic Digits test (DDT; Strouse & Wilson, 1999; Jerger & Martin, 2006). The SCAN 3:A is a commonly used clinical test battery for screening and diagnosing APD in adults. The SCAN 3:A is comprised of subtests that examine different auditory skills and auditory processes. The four diagnostic subtests include: 1) a filtered words test; 2) an auditory figure-ground test; 3) a competing words test; and 4) a competing sentences test. The MLD is a measure of release from masking. Thresholds to a 500 Hz tone in the presence of a narrowband of noise are measured in two conditions: S_0N_0 and $S_{\pi}N_0$. In the S_0N_0 condition, the 500 Hz tone is in-phase between the two ears, whereas in the $S_{\pi}N_0$ the 500 Hz tone is out-of-phase between the two ears. The MLD is the difference in threshold between the two conditions. The GIN is a measure of temporal processing. A series of noise bursts is presented with 0-3 gaps of silence embedded. The length of the gaps varies from 2-20 msec. The GIN is scored in percent correct identification of the gaps and the gap-threshold (shortest gap identified 4/6 times). The DDT is a measure of dichotic listening. The DDT presents 1-, 2-, and 3-pairs of dichotic digits (1-10, excluding 7). Half of the pair is presented to the right ear, and the other half of the pair is presented simultaneously to the left ear. The DDT is presented in two response condition: free recall and directed recall. In the

free recall condition, the listener repeats all digits heard, regardless of order. In the directed recall right condition, the listener repeats all digits heard from the right ear, while ignoring digits in the left ear. In the directed recall left condition, the listener repeats all digits heard from the left ear, while ignoring digits in the right ear. Percent correct is calculated for each ear and for 1-, 2-, and 3-pairs individually.

Hearing Aid Diary

Subjects were asked to wear the mild-gain hearing aids for a minimum of 4 hours per day and complete daily recordings of their experience. Each daily entry asked the following questions: ‘How many hours did you wear the hearing aids?’, ‘Were the hearing aids used in a quiet environment?’, ‘If so, do you feel like the hearing aids helped in the quiet environment?’, ‘Were the hearing aids used in a loud environment?’, and ‘If so, do you feel like the hearing aids helped in the loud environment?’. An extra comments section was provided at the bottom of each entry for subjects to write any additional thoughts about their self-perceived abilities with the use of the mild-gain hearing aids.

Hearing aid fitting and orientation:

The subjects were fit with behind-the-ear receiver-in-the-canal hearing aids (Widex Dream 440). The hearing aids were programmed using the Widex Compass GPS software to provide 5-10 dB of gain from 1000-4000 Hz for soft and moderate inputs. Real-ear probe microphone verification (Frye Fonix 7000) for a 65 dB SPL input was performed to ensure that the hearing aids were meeting the predetermined amount of insertion gain at all frequencies. The hearing aids were also programmed so that the MPO did not exceed 100 dB SPL. Average insertion gain for a 65 dB SPL input between 1000-4000 Hz is presented in Figure 1. The figure

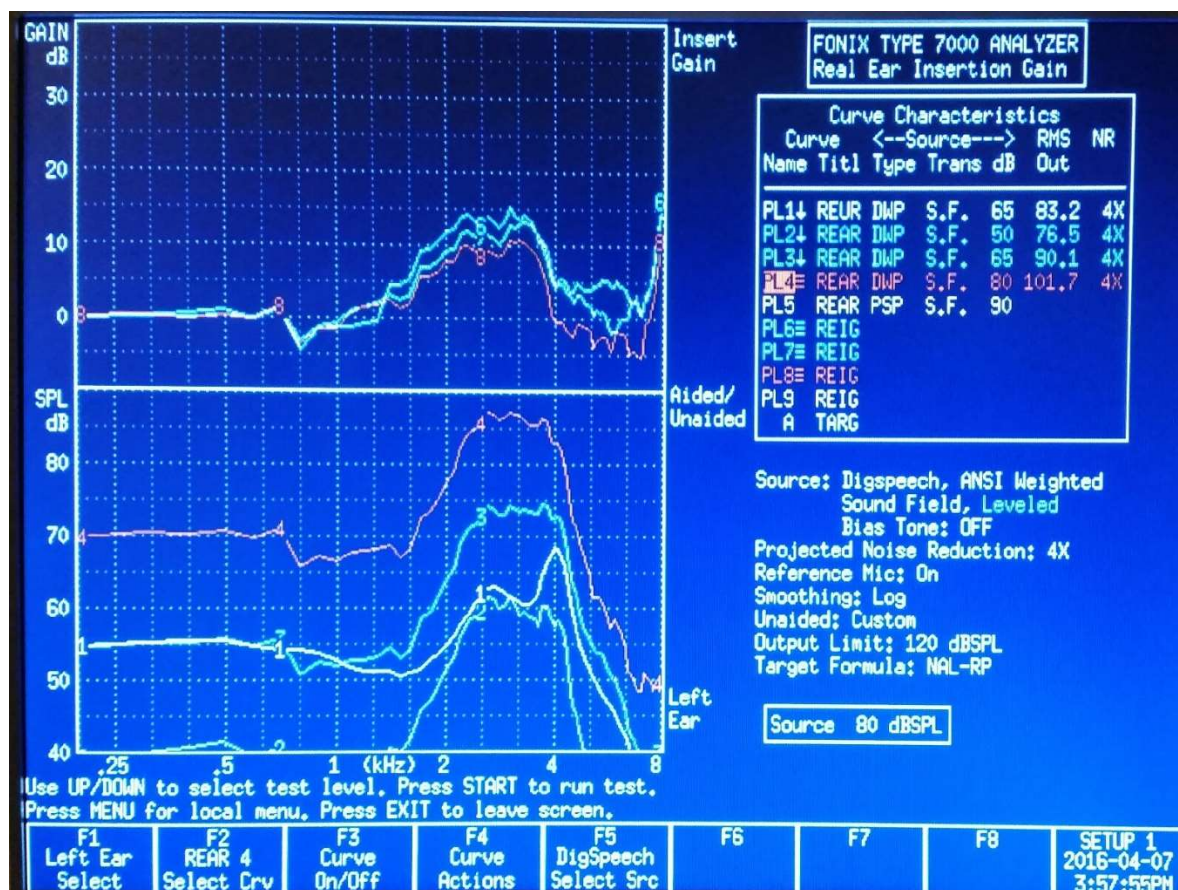
shows the real-ear, frequency-output response of the hearing aid to a 50 dB, 65 dB, and 90 dB SPL speech-shaped composite signal (Frye Fonix 7000). The hearing aids were also programmed with noise reduction enabled and directional microphones activated as this was found to provide the most benefit for the participants in the Kuk et al. (2008) study and was done so in the Moore (2015) study. Subjects were oriented in the use and care of the hearing aids after verification and were also provided with an information sheet explaining everything that was reviewed regarding the hearing aids.

Procedures:

Control subjects participated in only in one session. The control session was used to collect normative data on the subjective self-perceived hearing abilities questionnaires (i.e. HHIA and APQ) and the objective measure of speech-recognition in noise abilities (i.e. R-SPIN). The R-SPIN was tested at four signal-to-noise ratios (SNR): -12, -8, -4, and 0 dB SNR. The order of testing was randomized to avoid SNR and list effects. On completion of the R-SPIN, control subjects were asked if they experienced any anxiety during testing and answers were recorded.

HD subjects participated in three sessions. Session 1 was used to determine candidacy for the experiment and hearing aid trial. During Session 1, subjects completed the HHIA, APQ, and the auditory processing test battery (SCAN-3:A, GIN, MLD and DDT). If the subject qualified for the hearing aid trial, he/she was consented during Session 1. Session 2 consisted of unaided testing on the R-SPIN and the fitting and verification of the mild-gain hearing aids. The R-SPIN was measured at the same SNRs as the control group. After completion of the R-SPIN, HD subjects were also asked if any anxiety was experienced and answers were recorded. Subjects

Figure 1. Real-ear output of the hearing aid to a 50, 65, and 80 dB SPL speech-shaped noise.



were then oriented and provided with the hearing aid diary during the final portion of Session 2. During Session 3, aided testing on the R-SPIN was measured along with aided measures for both subjective questionnaires (HHIA and APQ). Each subject was then asked again if any anxiety was experienced during R-SPIN testing while using the mild-gain hearing aids.

Chapter 3

Results

HHIA and APQ – Control vs. HD:

Mean control and HD HHIA and APQ scores are presented in Table 1. As seen in Table 1, control subjects scored consistently lower than HD subjects when asked to rate both auditory processing abilities (i.e. APQ) and self-perceived hearing handicap (i.e. HHIA). In order to assess differences in hearing handicap between the groups, a one-way analysis of variance (ANOVA) was performed. Results revealed that HD subjects exhibited significantly greater hearing handicap than the control subjects ($F_{1, 15} = 50.5; p < 0.05$). Similarly, a one-way ANOVA was performed to assess differences in auditory processing (i.e., APQ). Results revealed that HD subjects exhibited significantly greater auditory processing difficulties than the control subjects ($F_{1, 15} = 24.4; p < 0.05$).

R-SPIN – Control vs. HD:

Mean R-SPIN recognition performance for control and HD groups is presented in Figure 2. Figure 2 compares R-SPIN recognition performance between the control and HD groups as a function of SNR with HP sentences in the left panel and LP sentences in the right panel. As can be seen in Figure 2, recognition performance on HP sentences was better than recognition performance for LP sentences for both groups. Similarly, R-SPIN recognition performance increased for both groups as a function of SNR (from -12 to 0 dB SNR) for both HP and LP sentences. Figure 2 also clearly demonstrates consistently poorer R-SPIN recognition performance for the HD group compared to the control group across SNRs and sentence type (HP and LP).

Table 1. Mean HHIA and APQ scores for the HD and control groups.

Subject group	HHIA Mean	APQ Mean
HD Group (n=7)	37.71	77.7
Control Group (n=10)	0	24.4

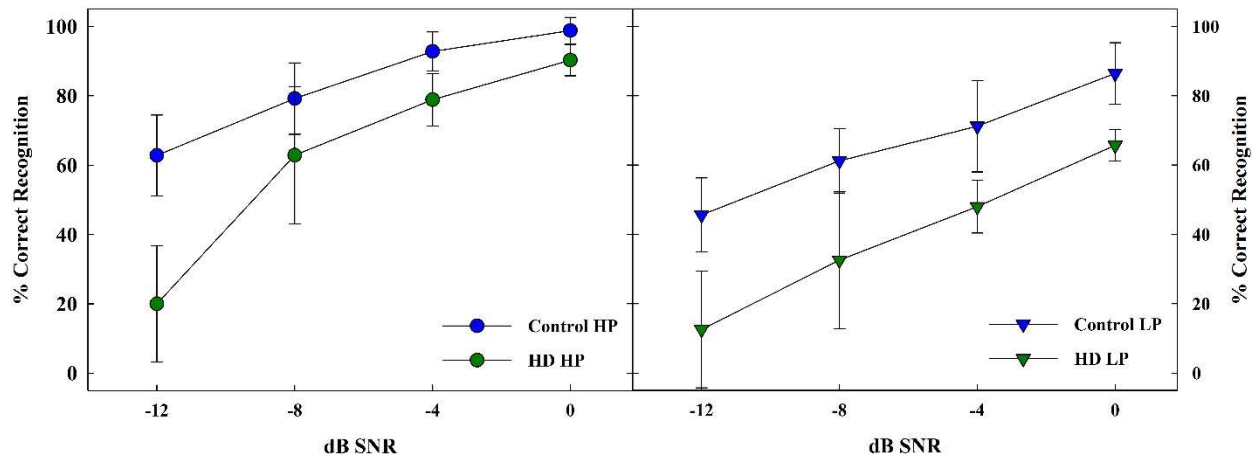


Figure 2. Mean R-SPIN recognition performance (in % correct) for Control (blue symbols) and HD (green symbols) groups as a function of SNR. Error bars represent one standard deviation. Recognition performance for HP sentences is presented in the left panel (circles) and for LP sentences in the right panel (triangles).

Prior to statistical analysis, the R-SPIN percentage data were transformed to rationalized arcsine units (raus) to correct for the error in variance associated with percentage data (Studebaker, 1985). R-SPIN recognition performance was analyzed using a repeated measures ANOVA with *group* as the between-subjects variable and *context* and *SNR* as the within-subjects variables. Results revealed a significant main effect of *group* ($F_{1, 15} = 39.1; p < 0.05$), confirming that the HD group performed significantly poorer than the control group for HP and LP sentences.

Results also demonstrated a significant main effect of *context* ($F_{1, 15} = 282.4; p < 0.05$). Specifically, subjects performed significantly better on HP sentences than LP sentences. Post-hoc paired samples t-tests with Bonferroni correction ($p < .006$) demonstrated that the control group performed significantly better on HP sentences than LP sentences across all SNRs. Similarly, the HD group performed significantly better on HP sentences than LP sentences for -8, -4 and 0 SNRs.

Finally, results demonstrated a significant main effect of *SNR* ($F_{3, 45} = 190.8; p < 0.05$). Post-hoc paired samples t-test with Bonferroni correction ($p < .004$) were conducted for each SNR pair for a total of 12 comparisons for each group. For the control group, post-hoc results demonstrated significantly better recognition performance with increasing SNR for HP and LP sentences with the exception of the -8 vs. -4 dB SNR comparison for LP sentences. For the HD group, post-hoc comparisons revealed significantly better recognition performance for the -8, -4, and 0 dB SNR conditions versus the -12 dB SNR condition for HP sentences. For LP sentences, the HD group performed significantly better between each SNR comparison with the exception of the -4 vs. 0 dB SNR comparison.

HHIA and APQ – HD unaided vs. aided:

Individual unaided and aided HHIA and APQ scores are presented in Table 2. As seen in Table 2, the majority of HD subjects scored consistently lower than their unaided performance when asked to rate both auditory processing abilities (i.e. APQ) and self-perceived hearing handicap (i.e. HHIA) with the use of the mild-gain hearing aids. However, two subjects rated higher HHIA scores and one subject rated a higher APQ score. In order to assess differences in hearing handicap (i.e. HHIA) between conditions, a one-way ANOVA was performed. Results revealed that there was no significant difference in hearing handicap between the unaided and aided conditions. Similarly, a one-way ANOVA was performed to assess differences in auditory processing (i.e., APQ). Results revealed that HD group exhibited no significant difference in auditory processing abilities between aided and unaided conditions ($F_{1, 15}; p > 0.05$).

R-SPIN – HD unaided vs. HD aided:

Mean unaided and aided R-SPIN recognition performance for the HD group is presented in Figure 3. Figure 3 compares R-SPIN recognition performance between the two conditions (i.e. unaided and aided with the mild-gain hearing aids) as a function of SNR with HP sentences in the left panel and LP sentences in the right panel. As can be seen in Figure 3, recognition performance on HP sentences was better than recognition performance for LP sentences in both unaided and aided conditions. Similarly, R-SPIN recognition performance improved for both

Table 2. HHIA and APQ scores of HD subjects in both conditions. Increased benefit scores (red numbers) were not included in the average benefit calculation.

	HHIA Unaided	HHIA Aided	HHIA Benefit (Unaided – Aided)	APQ Unaided	APQ Aided	APQ Benefit (Unaided – Aided)
	24	42	-18	111	89	+22
	34	20	+14	61	39	+22
	74	32	+42	118	77	+41
	34	2	+32	52	17	+35
	24	62	-38	37	65	-28
	34	4	+30	79	24	+55
	40	32	+8	86	69	+17
Average			= 29.5			= 35

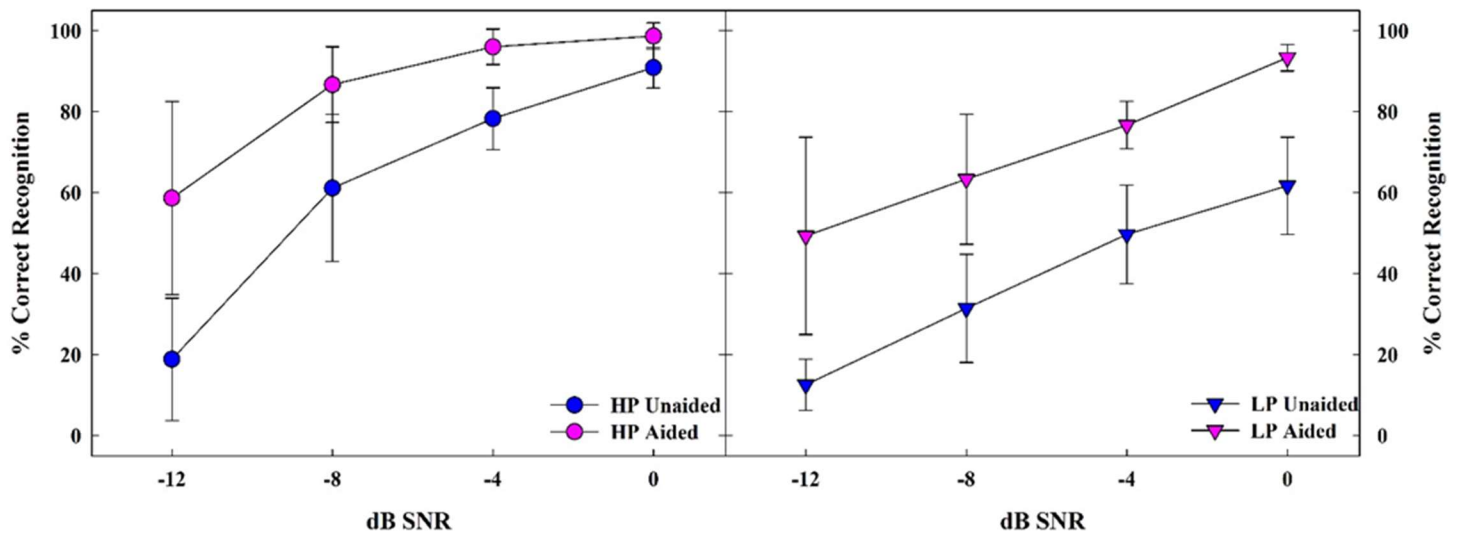


Figure 3. Mean R-SPIN recognition performance (in % correct) for HD unaided (blue symbols) and HD aided (pink symbols) conditions as a function of SNR. Error bars represent one standard deviation. Recognition performance for HP sentences is presented in the left panel (circles) and for LP sentences in the right panel (triangles).

conditions as a function of SNR (from -12 to 0 dB SNR) for both HP and LP sentences. As seen in Figure 3, HD group demonstrated consistently better R-SPIN performance in the aided condition relative to the unaided condition across all SNRs and sentence types (HP and LP).

R-SPIN recognition performance was analyzed using a repeated measures ANOVA with *hearing aid condition*, *context*, and *SNR* as within-subjects variables. Results revealed a significant main effect of *hearing aid condition* (i.e. unaided versus aided) ($F_{1,6} = 54.4$; $p < 0.05$), confirming that when aided, HD subjects performed significantly better than when unaided for HP and LP sentences.

Results of aided R-SPIN recognition performance demonstrated a significant main effect of *context* ($F_{1,6} = 293.5$; $p < 0.05$). Specifically, when aided, HD subjects performed significantly better on HP sentences than LP sentences. Post-hoc paired samples t-tests with Bonferroni correction ($p < .0125$) demonstrated that the aided HD group performance was significantly better on HP sentences than LP sentences across all SNRs.

Results also demonstrated a significant main effect of *SNR* ($F_{3,18} = 57.9$; $p < 0.05$). Post-hoc paired samples t-test with Bonferroni correction ($p < .008$) were conducted for each aided SNR pair for a total of 12 comparisons. For aided HD performance, post-hoc results demonstrated significantly poorer recognition performance for -12 dB SNR compared to -4 and 0 dB SNRs, but not significantly poorer than -8 dB SNR. Similarly, significantly poorer performance was found for -8 and -4 dB SNR as compared to 0 dB SNR. For the HP sentences, post-hoc comparisons revealed significantly poorer recognition performance for the -12 dB SNR compared to -8, -4, and 0 dB SNR conditions. For LP sentences, no other differences in recognition performance between SNRs were found.

Finally, results demonstrated a significant *context x SNR* interaction ($F_{3, 18} = 6.6$; $p < 0.05$). As seen in Figure 3, the rate of performance improvement was greater for HP sentences than for LP sentences. Specifically, the greatest rate of performance improvement can be seen between -12 and -8 dB SNR for HP sentences (i.e., 25%), whereas the LP sentence performance improved at a slower rate for same SNR comparison (i.e., 14%).

Hearing aid diary reports

During the four-week trial, HD subjects were asked to wear the mild-gain hearing aids for a minimum of four hours a day. Individuals were also given a hearing aid diary to record the number of hours they wore the hearing aids. Daily entries gave the following ranges to record hours of hearing aid use: 0 hours, 1-4 hours, 4-8 hours, and 8+ hours. The average hour range for each subject was calculated and is shown in Figure 4. As seen in Figure 4, four subjects (i.e. = 66% of HD subjects) wore the hearing aids on average 4-8 hours each day. Two subjects used the hearing aids for 1-4 hours each day (i.e. = 33% of HD subjects). These results demonstrate that the majority of individual wore the hearing aids either the minimum number of hours or more. This result revealed that the majority of HD subject had a substantial amount of time each day to experience potential benefits of the mild-gain hearing aids.

Anxiety – Control vs. HD

At the conclusion of each R-SPIN testing, both control and HD subjects were asked a question regarding their anxiety levels; “Did you experience anxiety during testing.” HD and

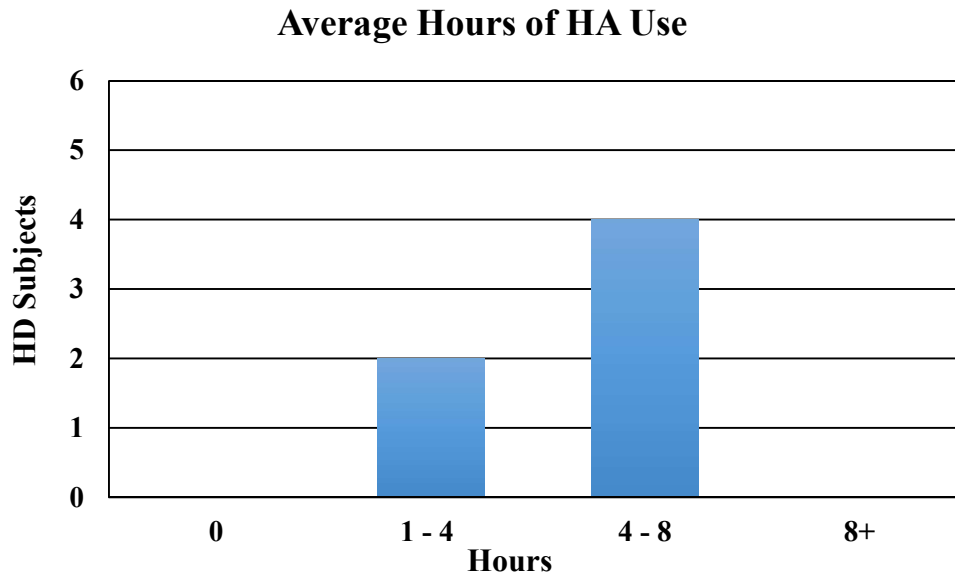


Figure 4. Average hours spent wearing the mild-gain hearing aids by each HD subject.

control responses were transcribed and reviewed. Responses for both control and HD groups are presented in Appendix A (control responses) and Appendix B (unaided and aided HD responses). Less than half of control subjects did not report experiencing any anxiety. Those who did (4 of 10 control subjects), reported minimum levels of anxiety during more difficult SNR levels (i.e. -8 and -12 dB SNR). Conversely, the majority of HD subjects reported anxiety (4 out of 6 HD subjects). Accounts of HD anxiety were also described more severely than control subjects. For example, one HD subject stated “Oh God yes,” while control subjects stated things such as; “A little. Maybe a 3 on a scale from 1 to 10.”

Not all HD subjects reported anxiety during unaided R-SPIN testing. HD subjects who did report anxiety during unaided testing reported differently after aided testing. As seen in Appendix B, feelings of anxiety were reduced or resolved while using the mild-gain hearing aids during R-SPIN testing.

Chapter 4

Discussion and Conclusions

The purpose of the present study was to examine the benefits of a four-week trial with mild-gain hearing aids for adults with subjective HD. It was hypothesized that with the use of mild-gain hearing aids, HD subjects would experience improvements in subjective hearing abilities (i.e., HHIA and APQ), improvements on an objective measure of speech-in-noise (i.e., R-SPIN) and decreased anxiety. It was also hypothesized that control subjects would perform significantly better on both objective (i.e., R-SPIN) and subjective measures (i.e., HHIA and APQ) when compared to the HD group.

Statistical analysis revealed that HD subjects did not show a significant improvement on subjective self-perceived auditory processing abilities (i.e., APQ) or hearing handicap (HHIA) when using the mild-gain hearing aids, thus failing to support the present study's hypothesis. Although the majority of subjects did experience improvements in subjective auditory processing abilities and hearing handicap, two subjects did not. Two subjects reported a higher hearing handicap (HHIA) and one subject reported more auditory processing difficulties (APQ) when using the mild-gain hearing aids. One subject described more difficulties with the hearing aids due to attention deficits. He recounted that the hearing aids overwhelmed him with auditory information causing him to rate a greater hearing handicap and poorer auditory processing abilities. It was unclear why the other subject only reported a higher hearing handicap and not higher auditory processing difficulties. The small sample size in the present study likely accounts for the lack of significant differences at the group level. With a larger sample size, this result could possibly change to a significant difference. The majority of subjects, however, experienced

improvements in subjective hearing abilities, validating the use mild-gain hearing aids as a potential treatment for those with HD in a subset of clinical patients.

Significant improvements on the objective speech-perception-in-noise task (i.e., R-SPIN) were seen in HD subjects when using the mild-gain hearing aids, therefore supporting the primary purpose of the study. Aided performance was significantly better than the unaided performance for HP sentences at -8 dB SNR, and for LP sentences at -12, -8, -4, and 0 dB SNRs. Speech-perception-in-noise improvements on a task where HD individuals experience the most difficulties also supports the use of mild-gain hearings for those with HD.

The present study asked subjects if they experienced any anxiety after speech-perception-in-noise testing. Four of six HD subjects and three of 10 control subjects reported anxiety during speech-perception-in-noise testing (see Appendix A & Appendix B). Not all HD subjects reported feelings of anxiety during unaided R-SPIN testing; however all those who did report anxiety in the unaided condition also reported experiencing no anxiety during aided R-SPIN testing. This observation supports the hypothesis that mild-gain hearing aids can potentially reduce feelings of anxiety in complex noise environments.

Between-group comparisons revealed that the HD group performed significantly poorer overall than the control group on both subjective self-perceived hearing abilities (i.e., HHIA and APQ) and objective measures of speech-perception in noise (i.e., R-SPIN). The difference in recognition performance on all test measures between groups suggests that individuals with subjective HD comprise a group other than “normal”. This result also confirms the hypothesis that the control group would perform significantly differently than the HD group on objective (i.e., R-SPIN) and subjective measures (i.e., HHIA and APQ).

Moore (2015) and Kuk et al. (2008) examined the benefits of the mild-gain hearing aids in populations similar to that of the present study and reported similar results. For example, performance improvements were observed between conditions (unaided vs. aided) on objective speech-perception-in-noise tasks (i.e. R-SPIN and ACPT in noise) for the present study, Moore (2015) and Kuk et al. (2008). However, the present study differed from both Moore and Kuk et al. in subjective measures between conditions. Kuk (2008) and Moore (2015) observed significant improvements in subjective auditory processing abilities and hearing handicap (CHAPS, R-CHAPS, and HHIA). The present study, however, did not observe a significant differences in subjective hearing abilities (i.e. HHIA and APQ) between conditions. The present study did see subjective improvements in hearing abilities among the majority of subjects when aided, however two subjects experienced higher subjective scores (i.e., poorer auditory processing abilities and a greater hearing handicap). The present study included only seven HD subjects, and this small sample size is likely the reason for the lack of significant statistical difference when comparing unaided and aided subjective results. Future testing should be conducted to more fully observe the potential self-perceived benefits of mild-gain hearing in adults with HD.

Tremblay et al. (2015) assessed individuals similar to the subjects recruited for the present study. Both the present study and Tremblay et al. enrolled subjects based on HHIA scores and required subjects to have pure tone thresholds within the normal range. The present study asked subjects to respond with an overall HHIA score of 20 or above, while Tremblay et al. used four specific questions from the HHIA that were also scored differently (see Appendix C). A score greater than or equal to four qualified the participant to fall in the “reported HD”

group. Using the HHIA questions seen in Appendix C and the specified grading style, all of the present study's HD subject qualify as an HD subject defined by Tremblay et al.

The present study and Tremblay et al. did differ in results when testing HD subjects and control subjects (e.g. individuals without subjective complaints and normal pure tone thresholds) on speech-recognition-in-noise tasks (present study; R-SPIN. Tremblay et al; word recognition in competing message). Tremblay et al., revealed no significant difference between control and HD subjects on word recognition in competing message (WRCM) testing, while the present study showed a significant difference between the groups on R-SPIN testing. However, presentation SNR levels of the WRCM and R-SPIN differed. WRCM lists were presented at a +8 dB SNR, while the present study presented the R-SPIN lists at 0,-4,-8, and -12 dB SNRs. The variation in presentation levels is likely the reason for the lack of difference between HD and control subjects in the Tremblay et al. study. Future testing should be conducted to more fully observe HD performance on speech-perception-in-noise tasks at both negative and positive SNR levels to further gauge HD hearing abilities.

Finally, Tremblay et al. did reveal that HD subjects were more likely to report symptoms of depression, have seen a doctor for hearing loss, have vision difficulties, and participate in loud hobbies (e.g. hunting and shooting guns). The present study, however, did not assess external and environmental factors in HD individuals. Tremblay et al. results indicate that future research should assess HD individuals on relevant factors such as; sociodemographic factors, environmental exposures, medical history, and health-related quality of life.

Clinical Implications and Future Research

Results of the present study suggest that individuals with subjective complaints regarding their hearing ability comprise a different population from ‘normal’. The differences found between the control group and the HD group suggest that individuals with HD should receive clinical consideration beyond the typical audiometric evaluation, regardless of normal pure-tone thresholds. Results from the present study also support the use of mild-gain hearing aids as a viable treatment option for individuals with subjective HD or individuals with APD. Therefore, HD individuals with a significant hearing handicap and normal pure-tone thresholds should be considered for various audiology rehabilitation services including hearing aid technology.

Future research should compare various treatment strategies for the HD population. For example, FM systems are often used for the treatment of both children and adults (Baran, 2002) with APD. A comparison of FM versus the use of mild-gain hearing aids is needed in order to determine the difference in potential benefits for each. Further research is also needed in assessing a multitude of factors in the HD populations (and other associated populations; i.e., APD, OAD, HHL). Other factors could include but are not limited to: attention, inhibition, working memory, listening effort, etc.

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Appendix A. Individual subject's verbal responses to the question "insert question" asked after R-SPIN testing.

After Control Testing: "Did you experience anxiety during testing?"
"No, not really."
"A little. Maybe a 3 on a scale from 1 to 10."
"No."
"Not at all really."
"No, not really."
"During the first session, but that was it." (Referring to -12 SNR)
"Nope."
"Not really. The first test was hard." (Referring to -12 SNR)
"Maybe during the first test?" (Referring to -8 SNR)
"Not really."

Appendix B. Individual subject's verbal responses to the question "insert question" asked after R-SPIN testing.

After Unaided Testing: "Did you experience anxiety during testing?"	After Aided Testing: "Did you experience anxiety during testing?"
"Oh God yes" Ranked a 6 out of 10	"Not really this time."
"Yes, I couldn't understand." (Referring to -12 SNR)	"Not at all because I could hear."
"No. I just thought can normal people hear this?"	"Not, just wanted to do well."
"Moderately, especially with the hard one." Referring to -12SNR	"No! I kept waiting for the hard test...but all of them were fine."
"Not really because I knew it would be hard."	"No."
"No, I know it's just a test"	"No."

Appendix C. Questions pulled from the HHIA by Tremblay et al. in order to identify HD subjects. To qualify as “reported HD” individuals must score a four or greater. “Yes” = 2 points, “sometimes” = 1 point, and a “no” = 0 points.

Tremblay et al. (2015) HHIA Questions
1. Does a hearing problem cause you difficulty when in a restaurant with relatives or friends?
2. Does a hearing problem cause you difficulty hearing/ understanding coworkers, clients, or customers?
3. Do you have difficulty understanding conversations when several people are talking?
4. How much does your hearing limit you from hearing when someone talks to you in a noisy, large group of people?